# Advanced MicroTurbine System


## Power when and where you need it

## Clean and simple

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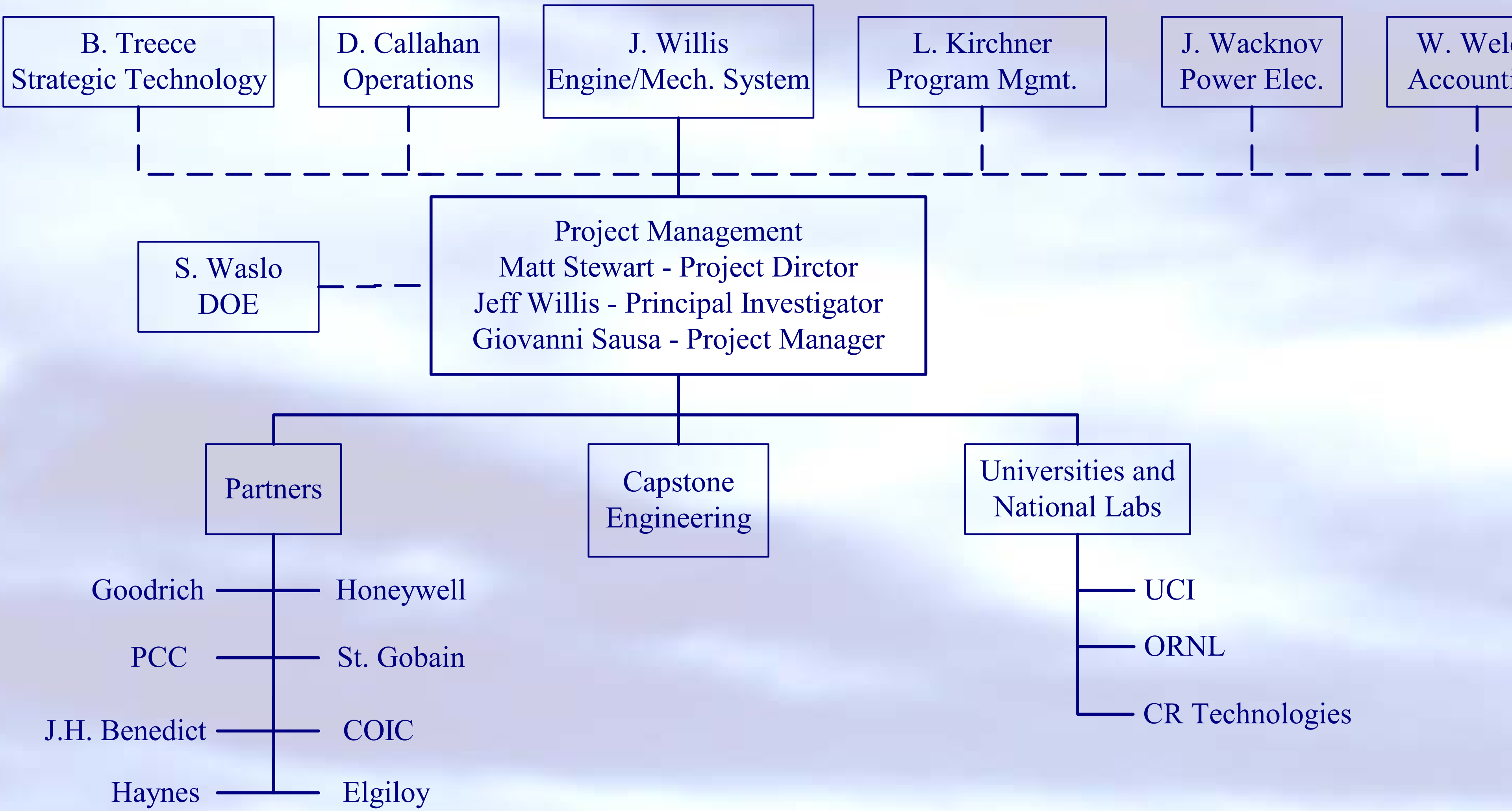
# Capstone High Efficiency AMTS

- Goals per DOE solicitation
  - Efficiency: > 40%
  - Cost: < 500 $/kW
  - Life: > 11k hours to overhaul, 45k service life
  - Multiple fuels
  - Emissions: < 7ppm NOx
- Capstone development plan
  - Complete development of Baseline Metallic Development (MD) system 1st
  - Introduce ceramics, advanced alloys, and high temperature recuperator to increase efficiency in Advanced High Efficiency (HE) microturbine system
  - HE system to meet DOE goals
  - MD system allows prudent stepped approach to validate majority of the system

# Project Overview

- Total project cost $23M, DOE share $10M
  - Substantial DOE contribution
- Requires development and partnering in areas that are not core competencies
  - Advanced materials:
    - ceramics (monolithic and composite)
    - single crystal superalloys
  - High temperature recuperator
- Considerable accomplishments to date
  - 8% of development in FY 2001
  - Emphasis on design, analysis, and rig development
  - On schedule per detailed plan

# Capstone Development Team

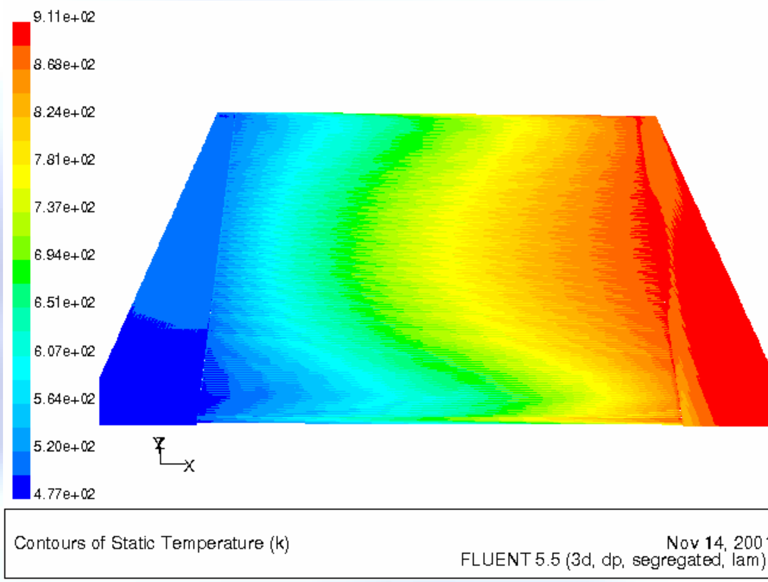


# Capstone AMTS Accomplishments FY 2001

- *Determine Advanced Microturbine system characteristics*
  - *Cycle studies*
  - *Subtask A: Market study*
- *Preliminary design*
- *Rig development*
- *Ceramic feasibility*
- *Preliminary recuperator design, producibility, and analysis*

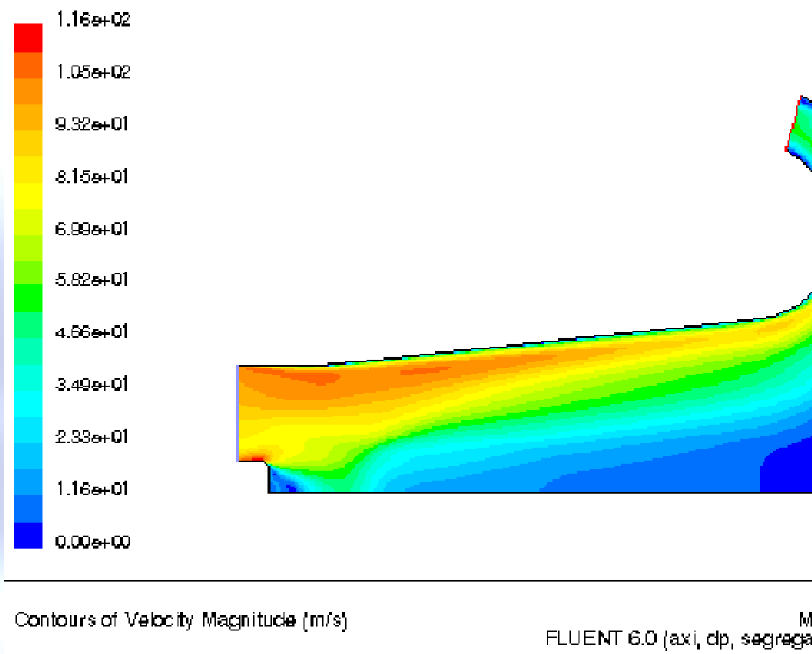
# Aerodynamic Cycle Studies

- *Extensive studies incorporating aerodynamic, recuperator, and cost models*
- *Similar model for High Efficiency (HE) and baseline Metallic Development (MD) systems*
- *Aerodynamic models: based on expected component efficiency, includes temperature limitations*
- *Study included single stage radial, single stage axial, 2 stage (single spool) axial turbine*
- *Recuperator model based on CFD analysis*
- *Cost model includes discrete steps base on material limitations*



# Cycle Study Results

- *Parametric studies: Pr, TET, recuperator, power*
  - *Determine: $\eta$, cost, flow, component sizes and temperatures*
- *Optimum pressure ratio 4-4.5 (for single stage design)*
- *Axial turbine: higher cost and reduced system efficiency*
- *40% System efficiency is challenging!*
  - *Requires optimal performance from all components*
  - *Must minimize pressure drops and losses*
- *Increasing power*
  - *Decreased $/kW*

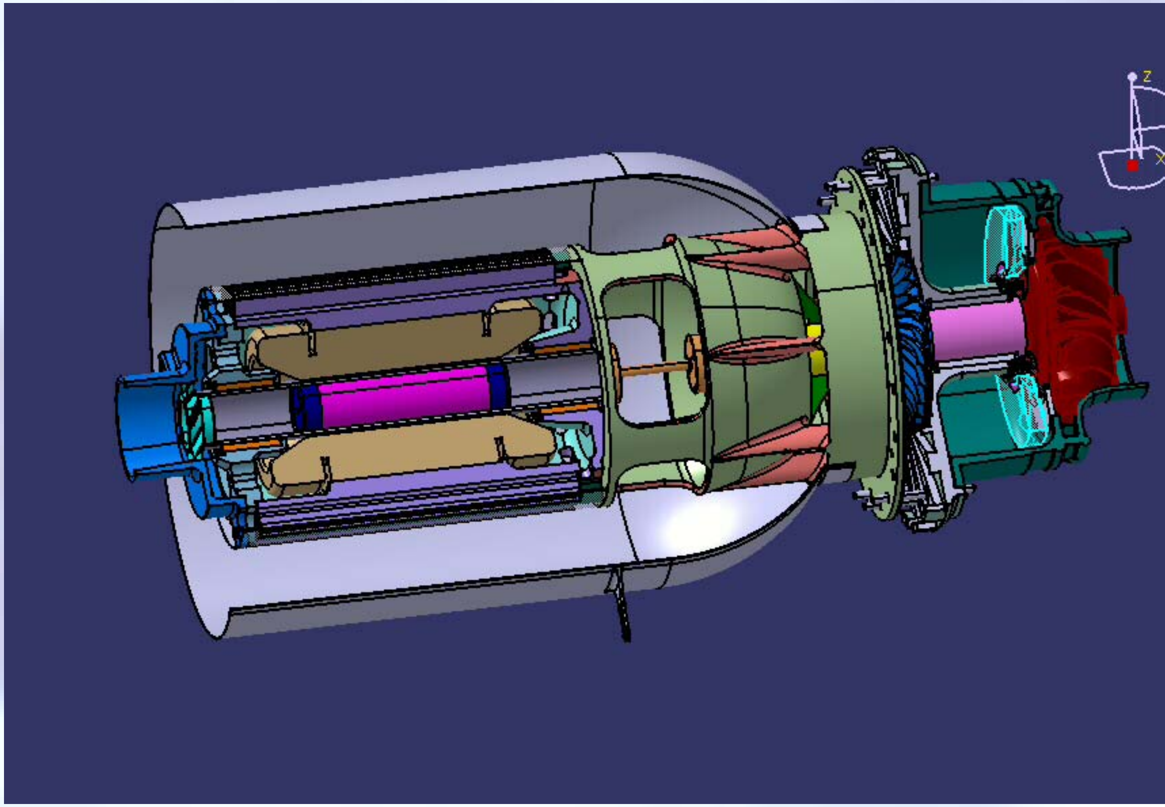


# Marketing Study Results

- *Significant market, multiple GW forecast*
- *Market potential based on installed costs, efficiency, O&M costs, gas price, and existing electricity price*
- *Minimum cost $.07/kWh for direct heating CHP, smallest market*
- *Largest market for peak shaving, $.14/kWh*
- *Minimal loss of market opportunities as power rating increased*

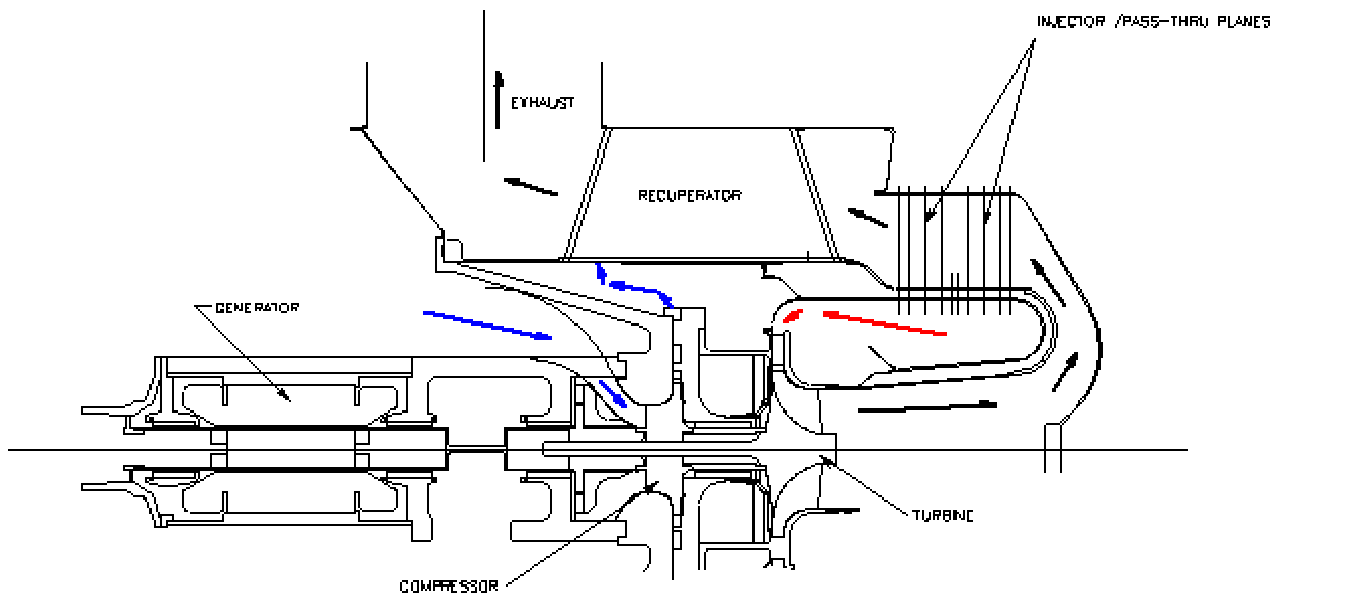
# Capstone Baseline Turbine

- *Single stage centrifugal compressor*
- *Single stage radial inflow turbine*
- *Powerhead and generator utilize same shaft*
- *Air bearings*



# System

- *Annular recuperator*
- *Annular low emission combustor*
- *IGBT based power electronics*
- *Full system approach*
- *Leverage experience from previous microturbine development projects*

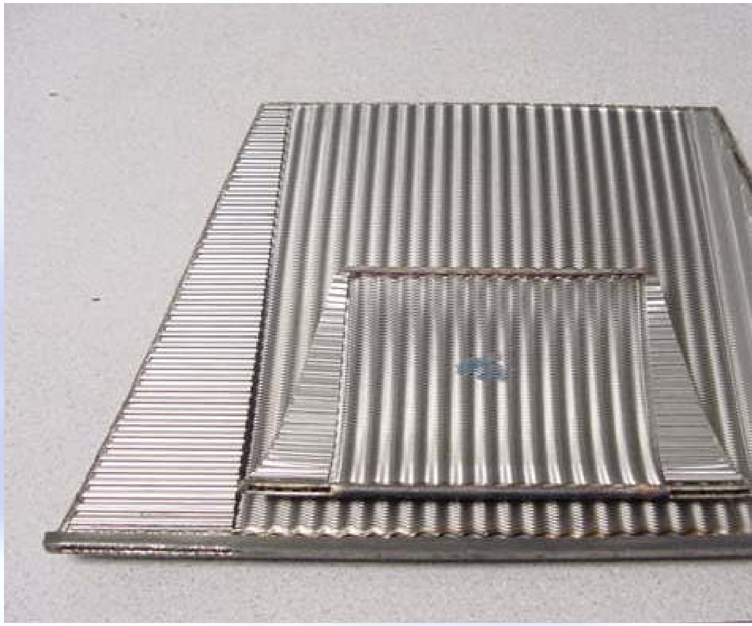


# Characteristics

| | Baseline MD | HE w/ ceramic rotor | HE w/ metallic dual-alloy |
|---|---|---|---|
| Power, kW | 200 | 290 | 270 |
| Net Efficiency | 35.0% | 40.8% | 40.3% |
| Cost relative to HE, $/kW | 75% | 100% | 100% |
| TET, °F | 1185 | 1600 | 1510 |
| Combustor | Metal | Ceramic | Ceramic |
| Recuperator | SS-347 | H214-230 | H214-230 |
| Overhaul life, hours | 45,000 | 11,000 | 11,000 |

# Recuperator development

- Similar to the configuration used on Capstone 30 kW and 60 kW
  - Successfully being manufactured by Capstone
  - No known failures after >1 million field operating hours
- Meets effectiveness and pressure drop requirements
- Improve manufacturability, decrease part count, improve welding
- Significant CFD analysis to optimize parameters
- Rig test to verify the design/analysis
- HE recuperator will require use of high temperature material
  - Materials identified for evaluation include HR-120, 230 and 214



# Advanced Material Insertion (HE System)

- *Modifications limited to engine hot section*
- *Turbine rotor: radial in flow, advanced material*
  - *monolithic ceramics*
  - *dual-alloy metallic*
- *Combustor design & temperature favor CFCC*
- *Turbine nozzle: ceramics or cooled metallic*
- *Focused effort in FY 2002*
  - *Radial turbine rotor fabrication feasibility*
  - *CFCC combustor material selection & evaluation*
  - *Remaining static design considered lower risk*

# Ceramics

- *Monolithic supplier uncertainty effected development*
- *Monolithic development*
  - *Continued dialog w/ potential partners*
  - *Component requirements and schedule identified*
  - *Radial turbine rotor thick hub and diameter are technical challenges*
- *Combustor CFCC's*
  - *Candidates materials identified*
  - *Select material and start sub-element ring testing in ORNL C60*

# Program Risks

- Recuperator
  - Performance: CFD analysis, rig tests, early engine tests
  - Life: weld evaluation, cyclic testing
  - High temperature materials: coordinated effort w/ manufacturers and ORNL
- Turbine
  - Evaluate the use of advanced cast materials
  - Continue to pursue monolithic ceramics
- Combustor:
  - Performance: advanced CFD and testing (rig/engine)
  - Advanced materials for HE system
- Aerodynamic cycle
  - Component testing (rig/engine)
- Overall (consistent w/ turbomachinery development)
  - Analysis, rig testing, early engine evaluation

# Near Term Goals

- *FY 2002*
  - *Complete Baseline MD system design*
  - *Complete initial recuperator core (SS347)*
  - *Initiate MD engine testing*
- *FY 2003 and Beyond*
  - *Complete Baseline MD system testing*
  - *Complete HE design*
  - *Complete first HE recuperator core*
  - *Initiate test of advanced material "hot section" components*
  - *Complete HE system testing*
  - *Complete field test HE system (Task 5)*

# Capstone AMTS Summary

- *Good progress to date*
- *Preliminary design of HE meets all defined goals*
- *Prudent stepped approach, near-term focus on MD system*
- *Introduce advanced materials*
- *Continue to advocate the use of Microturbine DER applications*